PATENT SPECIFICATION

(11) 1 246 142

DRAWINGS ATTACHED

(21) Application No. 44281/68 (22) Filed 18 Sept. 1968

(45) Complete Specification published 15 Sept. 1971

(51) International Classification H 03 k 13/00 G 06 g 7/18

(52) Index at acceptance

G1U 6
H4D 265 376 411 41X
H4L 26E1 26G2A 26H

1246142

(72) Inventor FRANK STEVEN GUTLEBER

(54) MEANS AND METHOD TO OBTAIN AN IMPULSE AUTOCORRELATION FUNCTION

(71) We, INTERNATIONAL STANDARD ELECTRIC CORPORATION, a Corporation organised and existing under the laws of the State of Delaware, United States of America, of 320 Park Avenue, New York 22, State of New York, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to correlation type pulse signalling systems, that is, signalling systems in which correlation techniques are used in the reception of coded pulse signals, and more particularly to an improved autocorrelation technique for use in such pulse signalling systems.

Correlation techniques have been utilized in the past in signal processing systems employing signals in the form of a pulse or sequence of pulses. Such pulse signalling systems include, for example, radiant energy reflecting systems, such as radar, radio range finders, radio altimeters, and the like; pulse communication systems, such as over-the-horizon systems employing various types of scatter techniques, satellite communication systems and the like; and multiple access systems employing address codes to enable utilization of the multiple access system. Correlation techniques when employed in radiant energy reflection systems enhance the resolution of closely spaced reflecting surfaces and in addition, particularly when wide pulse widths are employed, increase the average power transmitted. Correlation techniques employed in pulse communication systems result in increased signal-to-noise ratios without increase of transmitter power and minimized multiple path effects (fading). Correlation techniques when employed in a multiple access environment also result in increased signal-to-noise ratio without increase of transmitter power, and if the transmitted signals are properly coded prevent or at least minimize the interference or crosstalk between one or more address codes.

According to prior art correlation techniques the received signal is processed by obtaining the product of code elements of the received signal and code elements of a locally generated signal of the same wave form and period as the received signal and integrating the resultant product. The optimum output for such a correlation would be a single peak of high amplitude which has a width substantially narrower than the pulse width of the received signal. Most correlation systems in use today do not produce the desired optimum waveform, but rather provide an output whose waveform has spurious peaks in addition to the desired high amplitude peak. The presence of these spurious peaks is undesirable in that the resolving power of radiant energy reflecting systems is reduced, and the signal-to-noise ratio of pulse communication systems and multiple access systems and the minimization of multiple path effects of pulse communication systems are all reduced to levels below the optimum value.

Previously a number of improved correlation techniques have been proposed that will result in an impulse correlation function when the received signal is suitably detected. The term "impulse correlation function", and more specifically "impulse autocorrelation function", as employed herein, refers to a correlation waveform after detection having a single high amplitude peak completely free from spurious peaks of lower amplitude elsewhere in the waveform.

One of these previous correlation techniques requires the generation of a first sequence of coded pulses, a replica of this first sequence of coded pulses, and a second sequence of coded pulses. The first and second sequences of coded pules are each separately correlated with the replica of the first sequence of coded pulses to produce

from each correlation separate correlated outputs which in turn are correlated to produce the impulse corelation function. The first and second sequences of coded pulses each have a distinctive code pattern so that when one of the correlated outputs has a finite value the other correlated output is zero resulting in a zero output when these correlated outputs are correlated one with the other except when the first and second sequences of coded pulses are in time coincidence with the replica of the first sequence of coded pulses.

A second of these previous correlation techniques to obtain an impulse correlation function requires the production of a sequence of coded pulses having a predetermined pattern so that when this sequence of coded pulses and its replica are correlated a zero output will result at all times except when the sequence of coded pulses and its replica are in time coincidence.

The disadvantage of the first correlation technique above-described is that of requiring the production of a second sequence of coded pulses to ensure that when the first sequence of coded pulses and its replica are correlated and produce a finite output, the correlation between the second sequence of coded pulses and the replica of the first sequence of pulses is zero so as to produce a zero output in a third correlation process ("forcing technique").

In the second correlation technique above described, the performance is optimum until it is desired to employ an extremely long sequence of coded pulses to increase the average power transmitted. Then it becomes very tedious and requires a complex coding arrangement to generate the code that will provide the desired impulse correlation function and increased average transmitted power.

Correlation type pulse signallnig systems, and particularly correlation systems employed in a multiple access system, require coded signals which contain good cross correlation properties to minimize self interference or cross talk between the various codes employed. To obtain the good cross correlation properties of codes employed in correlation detection systems the codes should have a pseudo-noise characteristic. The reason for employing codes having this characteristic is to ensure that an interfering code is rejected in proportion to the ratio of the spectrum bandwidth to the information bandwidth on the average. A pseudo-noise code to be employed in the present invention should also have an autocorrelation function including a peak amplitude in a time interval equal to the smallest code bit length and zero everywhere else.

Previously phase codes whose autocorrelation function is essentially an impulse autocorrelation function have been discovered. To accomplish the results desired necessitated a minimum of four phases which resulted in achieving an aperiodic impulse response. That is, a cyclic closed code was not necessary to yield the desired result.

Another type of code having good periodic correlation properties is the so called linear maximal length code sequences. These codes are comparatively easily generated with shift registers and modulo two adders. Using K shift registers, code lengths of (2^K-1) bits are generated and the available quantity of unique codes capable of being obtained in a stipulated time-bandwidth product $TW=(2^K-1)$ is

$$\frac{\phi(2^K-1)}{K} \qquad (1)$$

where $\phi(x)$, the Euler phi-function, is the number of integers less than x which are prime to x; in this case, $x=(2^K-1)$; T=the information sampling period and W= the carrier bandwidth. The autocorrelation function $\phi_{11}(t)$ of this class of codes is given by

$$\phi_{11}(t)=\frac{1}{N},$$

where N=the number of code bits in a TW period, or

$$N=2^K-1.$$

Two distinct cases arise:

(a) $\phi_{11}(t)=1$ for $t=0, N, 2N \ldots$ etc. (time coincidence) (2)

$$\text{(b)} \quad \phi_{11}(t)=\frac{1}{2^{K}-1} \text{ for } t\neq 0,\ N,\ 2N,\ \ldots \text{ etc. (time displacement)} \quad (3)$$

where t=the bandwidth of a single code bit and has a discrete value related to the number of code bits separating the code and its replica in the autocorrelation process. Since

$$\frac{1}{2^{K}-1}=\frac{1}{TW}=\frac{1}{N},$$

the amplitude of the autocorrelation function is reduced by a sufficient amount (for large time-bandwidth products) to be considered negligible. In addition, it remains at a negligible level until the code is repeated. It will be immediately apparent that this actually is not an impulse autocorrelation since there are spurious peaks in the autocorrelation functions of these types of codes.

The previous discussion of pseudo-noise codes has been limited to the autocorrelation properties thereof. The advantage of a pseudo-noise code is found in its cross correlation properties. If the codes are like noise, then the rms value of the cross correlation function should be reduced by $\sqrt{TW}$ from its autocorrelation value at t=0, that is, when the code and its replica are in time coincidence. Thus, the interfering code would be reduced in magnitude by this ratio, so called "protection ratio", on the average.

Useful background information is provided by the patent specifications related to these prior disclosures, namely British Patent Specification No. 1073024 and 1140590, as well as in numerous papers published around 1950 in the United States in Proc. I.R.E., and by P. M. Woodward in a textbook: "Probability and Information Theory with Applications to Radar" (Pergamon Press, 1953).

An object of the present invention is to provide a class of coded signals and an arrangement of detecting these coded signals which will overcome the disadvantages mentioned above in the previous arrangements producing an impulse correlation function.

According to the present invention, there is provided a correlation type pulse signalling system in which binary coded signals are used, the signals being so coded as to provide pairs of co-operating "code-mates", the mates of any given pair having predeterminedly-related and co-operating auto-correlation functions whereby upon transmission of signals corresponding to a given pair of "code-mates" to a distant receiver and detection of the individual "mates" of the pair upon reception thereat by respective autocorrelation detectors, followed by linear addition of the respective detector outputs, an "impulse auto-correlation function" (as herein defined) is derived, providing an impulse output at a given time and zero output at all other times within the periodic time of a coded signal comprising a pair of "code-mates".

Further according to the invention, there is provided a method of deriving coded signals for use in the system described in the preceding paragraph which comprises generating a plurality of binary coded signals each having a different given autocorrelation function the coding being such that some coded signals are "code-mates" of others, and selecting at least some of said generated signals to provide signal pairs of "code-mates" such that on detection of the two individual "code-mates" of a pair, the auto-correlation functions of the detected signals may be added to produce an impulse auto-correlation function for each said pair.

Still further according to the invention, there is provided a detector for use in the receiver of a system described in the last but one preceding paragraph for providing an impulse auto-correlation function at its output when connected at its input to a source of both a first code signal having a first auto-correlation function and a second code signal having a second auto-correlation function predeterminedly related to said first auto-correlation function in such a way that the combined auto-correlation functions when linearly added form an impulse function including an impulse at a given time and zero at all other times within the periodic time of either signal, comprising:

first means coupled to said source to separately autocorrelate said first and second code signals; and

second means coupled to said first means to combine the resultant signals of said autocorrelation to produce said impulse autocorrelation function.

The invention will now be more particularly described with reference to the accompanying drawings illustrating the derivation of suitable code formats for use in a correlation type pulse signalling system, and suitable detectors for such codes. In the drawings:—

Fig. 1 is a tabulation of unique code signals obtainable from an eight bit code and their respective autocorrelation functions permitting the identification of code mates in accordance with the principles of this invention;

Fig. 2 is a diagrammatic illustration of the manipulation of a pair of code mates necessary to increase the number of code mates;

Fig. 3 is a tabulation of the code mates generated in accordance with Fig. 2 and their respective autocorrelation functions;

Fig. 4 is a tabulation of code mates that may be generated from another code mate of Fig. 1 when manipulated as taught in Fig. 2 and their respective autocorrelation functions;

Fig. 5 is a tabulation of code mates that may be generated from the other code mates of Fig. 1 when manipulated in accordance with Fig. 2 and their respective autocorrelation functions;

Fig. 6 is a diagrammatic illustration of code mates generated from the first code mates of Fig. 3 in accordance with the principles of this invention and their respective autocorrelation functions;

Fig. 7 is a block diagram of a transmitter employing time multiplexing techniques for transmitting any of the code mates described with respect to Figs. 1 to 6;

Fig. 8 is a block diagram of a time multiplex receiver cooperating with the transmitter of Fig. 7 in accordance with the principles of this invention;

Fig. 9 is a block diagram of a transmitter employing frequency multiplexing techniques for transmitting the code mates described with respect to Figs. 1 to 6;

Fig. 10 is a block diagram of a frequency multiplex receiver co-operating with the transmitter of Fig. 9 in accordance with the principles of this invention;

Figs. 11 to 18 are diagrams illustrating that an impulse autocorrelation function is actually produced in accordance with the principles of this invention;

Fig. 19 is a block diagram of a code source in accordance with the principles of this invention that may be employed as the code source of Figs. 7 through 10; and

Fig. 20 is a curve illustrating the cross correlation properties of the code class generated in accordance with this invention.

While the description of the preferred embodiments is directed to multiplexing the code mates on either a time or frequency basis, it should be noted that the technique described herein will produce the results desired where the code mates are not multiplexed but rather are sent over separate transmission paths such as different wires or cables. In radio transmission, multiplexing is necessary in order to obtain the separate mate code pairs orthogonal to each other.

The pseudo-noise code class of this invention employs a structure approaching the simplicity of the maximal length code class and yet is capable of providing the impulse correlation function of the multiphased codes of the prior art. The codes of this code class are simple binary sequences which when properly detected yield an impulse autocorrelation function. The required detector of this code class depends on whether time or frequency multiplexing is employed. Each has its particular advantages, but either method of multiplexing would work equally well with the code class of this invention. A requirement imposed on the code pairs or mates for obtaining an impulse autocorrelation function in accordance with the principles of this invention is that the sum of their individual autocorrelation functions be zero for all values of $t \neq 0$, N, 2N, 3N, etc. The specific code mates to be utilized must have autocorrelation functions including a main peak in the first bit of the code, zero in other time coincident time positions of the code mates and spurious peaks in other time coincident time positions of the code mates having equal magnitude but opposite polarity. This is not too severe a restriction considering that a code with large spurious peaks in its autocorrelation function may be successfully utilized.

The following analysis identifies how many possible code mates exist for an eight bit binary sequence and also indicates what they are. The cross correlation properties of the code mates are shown to behave similarly to noise so that when the codes of this code class are properly detected there would result a good set of codes for correlation detector type systems, particularly multiple access systems.

In a binary code sequence of eight bits, $2^8=256$ possible code combinations exists. Of this comparatively large quantity, however, only 19 are what could be classified as unique and distinctive in a comma-free code. This is verified below.

The number of possible binary states is:

$$\sum_{p=0}^{p=N} \frac{N!}{p!(N-p)!} = 2^N \qquad (4)$$

where p=number of "1"s and N=number of code slots.

Two of these codes (all "0" or all "1") are trivial and may be disregarded, reducing the number of codes to:

$$\sum_{p=0}^{p=N} \frac{N!}{p!(N-p)!} - 2 \qquad (5)$$

Of these, each code arrangement is repeated "N" times with time shifts of 1 to N so that, in an endless sequence ("comma-free"), each time-shifted arrangement becomes indistinguishable from the others. Therefore, the quantity of unique codes becomes:

$$\frac{1}{N}\left[\sum_{p=0}^{p=N} \frac{N!}{p!(N-p)!} - 2\right] \qquad (6)$$

Disregarding complementary codes necessitates dividing the above quantity by 2. The number of unique codes q therefore becomes:

$$q = \frac{1}{2N}\left[\sum_{p=0}^{p=N} \frac{N!}{p!(N-p)!} - 2\right] = \frac{2^N - 2}{2N} \qquad (7)$$

Strictly speaking this equation is only accurate for odd length sequences since every code of the subset at p=a has a complement at p′=N−a, where p′≠p. For even length sequences, one code subset at p=N/2 contains in its own subset the complementary codes many of which have already been ruled out as time shifted codes. A more accurate expression for even length sequences would be given by:

$$q = \frac{1}{N}\sum_{p=1}^{p=\frac{N}{2}} \frac{N!}{p!(N-p)!} - e \qquad (8)$$

where e=quantity of complementary codes not accounted for in the time shifted codes at p=N/2.

Solving this equation for N=8 resulted in q=21−e, and for the subset of codes at p=4, e was found to be equal to 2. Hence q=21−2=19 unique codes.

These 19 codes are illustrated in Fig. 1 with their associated autocorrelation functions times N, the autocorrelation function being derived from:

$$\phi_{aa}(t) = \frac{1}{N}\sum_{n=1}^{n=N} a_n\, a_{(n+t)}, \qquad (9)$$

this being the generalized expression of the more usual form $\phi_{11}(t)$ of the function between a code format and its replica. In this instance, a_n and $a_{(n+t)}$ represent each of the 19 code formats having an arbitrary number *a* of "1"s, and its replica shifted *t* time positions, respectively, and the summation over the range n=1 to n=N is taken for each value of *t* from 0 (coincidence) to N−1 (that is, one position before the next coincidence).

Thus, each code format yields eight values of the correlation function, multiplied by N (in accordance with the transposed equation (9)), each being derived for a value of t increasing from 0 to 7 time positions. These correlations are made on a multiplicative basis using conventional logical relations, and are described in greater detail hereafter with reference to Figures 11 to 18 showing the operations in respect of two of the code formats, namely #4 and #14. Each of these figures shows a summation for Output Multiplier 34 (for #4), and for Output Multiplier 35 (for #14), respectively, which supply successively the components of the autocorrelation function in the horizontal line opposite the format in Figure 1 for the various values of t from 0 to 7.

In this way, the right-hand eight colums of Figure 1 are built up from the left-hand columns.

An inspection of the autocorrelation function times N of the codes of Fig. 1 revelas that there pairs exist which contain the necessary properties in accordance with the principles of this invention for generating an impulse autocorrelation function. These codes are codes #2 and #16, codes #3 and #15, and codes #4 and #14. These results demonstrate that for a time bandwidth product of 16 (8 bit positions and 2 frequencies, or 2 times when multiplexed) there is available $3\times2=6$ unique codes. A maximal length code when generated with four shift registers produces only a maximum of two unique codes as derived from equation (1). The code class in accordance with the principles of this invention, therefore, increases the available quantity of unique codes when compared with the maximal length code class in addition to achieving $\phi_{11}(t)=0$ for all $t\neq0$ in one code period.

As illustrated in Fig. 1, there are only three code mates that have the proper autocorrelation function relationship to provide the desired impulse autocorrelation function. This number of code mates can be increased by properly manipulating the three code mates to form new code mates of length 2N from any existing code mates of length N. This is accomplished by interleaving the original code mates to form one of the new code mates. The second code of the new code mates is obtained by interleaving the original code with the negative or complement of its mate. As will be proven, these two new codes must then form code mates having the characteristic of the code class of this invention. This process may be continued indefinitely to obtain code mates of length 2^M, where M is an integer.

Referring to Fig. 2, there is illustrated therein in diagrammatic form the process employed in generating new code mates from the code mates code #4 and code #14. Row A, Fig. 2, is the code format of code #4 and row B, Fig. 2 illustrates the code format of code #14. Row C, Fig. 2, illustrates the negative or complemented version of code format #14. By interleaving the code formats of rows A and B, Fig. 2, a new code format is generated identified as A4 illustrated in row D Fig. 2. The mate of code A4 is obtained by interleaving code format #4 (row A) and complemented code format #14 (row C) resulting in code format A4′, the mate of code format A4. To increase further the number of code mates, code format #4 is delayed successively by different integral amounts of t (the bit width). A delay of t is illustrated in row F. Fig. 2. When this delayed code format is combined with code format #14, a new code format B4 is generated (row G) and by interleaving the delayed code format #4 (row F) with the complemented code format #14 (row C) the code mate of code format B4, identified as code format B4′, is generated and illustrated in row H. This process can be continued with other discrete delays of code format #4 with each discrete delayed code format #4 being interleaved with code format #14 to form one code format of new code mates and interleaving the discretely delayed rode format #4 with the complemented code format #14 to form the other code format of the code mates as is clearly illustrated in Fig. 2. The result of this process illustrated in Fig. 2 is tabulated in Fig. 3 along with the autocorrelation function of each of the generated code formats multiplied by N. It is obvious from the inspection of the N$\times$the autocorrelation function of the newly generated code mates generated from code formats #4 and #14 that these code mates actually do meet the requirement placed on code format making up code mates as set forth hereinabove.

By employing the process illustrated in Fig. 2 for the code formats #2 and #16 of Figure 1, a new set of code mates may be generated with these code mates, their autocorrelation functions times N being tabulated in Fig. 4.

Again, employing the process of Fig. 2 with code formats #3 and #15 of Figure 1, other code mates are generated as tabulated in Fig. 5 with their corresponding autocorrelation function times N.

The procedure for generating long code signals has been outlined and illustrated

with respect to Figs. 2 to 5 without mathematically verifying that the concept must always work. This has been done to demonstrate how code pairs of large time bandwidth products are obtained. A general mathematical treatment with verifies that the proposed process must yield new mate pairs is set forth hereinbelow.

A mate pair is defined as two code signals of length N whose periodic autocorrelation functions contain one main peak, zero amplitudes and spurious peaks occurring in coincident bit slots with the magnitudes of the spurious peaks being equal but opposite to each other for all $t \neq 0$, N, 2N, etc. A new mate pair of length 2N may be generated from the code mates of length N. This is accomplished by interleavnig the original code mates to form one of the new code signals (or formats). The second new code format is then obtained by interleaving the original code format with the negative or complement of its mate. It will now be proven that these two new code formats must form a mate pair.

Consider a code format A given by:

$$A = a_1\ a_2\ a_3\ a_4\ \ldots\ a_N \tag{10}$$

Now postulate the existence of a second code format B of length N which forms a mate with code format A:

$$B = b_1\ b_2\ b_3\ b_4\ \ldots\ b_N \tag{11}$$

If A is interleaved with B, a new code format of length 2N is generated. This new code format is identified as code format C:

$$C = a_1\ b_1\ a_2\ b_2\ a_3\ b_3\ \ldots\ a_N\ b_N \tag{12}$$

The autocorrelation function for code format C may be written in a general form as:

$$\phi_{CC}(t) = \frac{1}{N}\sum_{i=1}^{i=N} a_i a_{(i+t/2)} + \frac{1}{N}\sum_{i=1}^{i=N} b_i b_{(i+t/2)} \tag{13}$$

when t is even.
And

$$\phi_{CC}(t) = \frac{1}{N}\sum_{i=1}^{i=N} a_i b_{\left(i+\frac{t-1}{2}\right)} + \frac{1}{N}\sum_{i=1}^{i=N} b_i a_{\left(i+\frac{t+1}{2}\right)} \tag{14}$$

when t is odd.

The negative or complement of code format B, code format B, will also be a mate to code format A since its autocorrelation function would be exactly the same as for code format $\bar{B}$. Code format B may be expressed as:

$$\bar{B} = \bar{b}_1\ \bar{b}_2\ \bar{b}_3\ \bar{b}_4\ \ldots\ \bar{b}_N \tag{15}$$

Interleaving code format A with code format $\bar{B}$ results in code format D:

$$D = a_1\ \bar{b}_1\ a_2\ \bar{b}_2\ a_3\ \bar{b}_3\ a_4\ \bar{b}_4\ \ldots\ a_N\ \bar{b}_N \tag{16}$$

And the autocorrelation function of code format D would be:

$$\phi_{DD}(t) = \frac{1}{N}\sum_{i=1}^{i=N} a_i a_{(i+t/2)} + \frac{1}{N}\sum_{i=1}^{i=N} \bar{b}_i \bar{b}_{(i+t/2)} \qquad (17)$$

when t is even.
And

$$\phi_{DD}(t) = \frac{1}{N}\sum_{i=1}^{i=N} a_i \bar{b}_{(i+\frac{t-1}{2})} + \frac{1}{N}\sum_{i=1}^{i=N} \bar{b}_i a_{(i+\frac{t+1}{2})} \qquad (18)$$

when t is odd.

Since code formats A and B form code mates, and code formats A and $\bar{B}$ form code mates, both equations (13) and (17) must always sum to zero. Therefore, the autocorrelation function of each new code format would always be zero for even values of t. The magnitude for odd values of t is given by equations (14) and (18). And since:

$$a_i b_j = -a_i b_j$$

then:

$$\phi_{DD}(t) = -\phi_{CC}(t) \text{ for all } t \neq 0.$$

Equations (7) and (8) were utilized to identify the quantity of unique code signals (time translated code formats and complementary code cormats being excluded) existing in any binary sequence of length N. As pointed out hereinabove, six unique code formats having the properties necessary for carrying out the invention, i.e. three mate-pairs are present for an eight-bit sequence. It was not an unreasonable task to establish every mate pair by computing the autocorrelation function for each of the 19 code formats. However, this procedure becomes unreasonable for longer code lengths. As an example, a 16-bit code would contain approximately 2,000 unique binary code sequences out of a total of $2^{16}=65,536$ binary codes. The code extension method outlined hereinabove with respect to Figs. 2 to 5 identifies a large portion of the available unique codes in a simple systematic manner. It was shown that a total of three code mates existed in an eight-bit sequence. Therefore, for each pair of code mates, or $8\times8=64$ code pairs, 16-bit codes may be established. This occurs since any code format may be interleaved with any time shift of its mate. In some cases duplicate code formats may result; however, every pair generated this way would yield a mate pair. Since this is so, it would be worthwhile to determine all the mate pairs obtainable by the proposed process and then eliminate any duplication. In the 16-bit sequence, a total of $64\times3=192$ code mates may be readily generated. Twenty four of the available codes and their autocorrelation functions times N have been tabulated in Figs. 3, 4 and 5 in sets of eight. An examination of the twenty four code formats which were generated in accordance with the technique of Fig. 2 and tabulated in Figs. 3, 4 and 5 reveals that they are all unique. All of these code formats including their time shifts are different. This is in spit of the fact that a number of the code formats have the same N-times-autocorrelation function. It is also possible to pair the code formats differently than as illustrated in Figs. 3, 4 and 5. For instance, code format D3 may be used to form a mate with C3, or E3 may be paired with either A3 or B3 rather than E3′. The fact that the resulting code formats tabulated in Figs. 3, 4 and 5 may be paired many different ways adds to the versatility of the code class.

The foregoing demonstrates that a minimum of twenty unique code formats exist (which becomes 48 due to multiplexing) with a possibility of realizing 168 more unique code formats (or 336 due to multiplexing). Establishing a unique quantity of code formats between 48 and 384 for a time bandwidth product of 32 is quite significant. Only 6 unique code formats are available in the maximal length code class for a time bandwidth product of 31.

As a point of interest, a 32-bit mate pair was generated from the 16-bit mate pair made up of code formats A4 and A4′. The resulting 32-bit code mates are illus-

trated in Fig. 6 along with their autocorrelation function multiplied by N. Code A was obtained by interleaving code format A4 with code format A4′. Code A′ was obtained by interleaving code format A4 with the negative or complemented code format A4′.

Referring to Fig. 7, there is illustrated therein a block diagram of a transmitter employed in a time multiplex arrangement in accordance with the principles of this invention. Code source 20 generates signals representing codes S1 and S2, where codes S1 and S2 are those codes that make up code mates. Code signal S2 is coupled directly to modulator 21 to modulate the output of carrier source 22 at a frequency f. Code signal S1 is coupled through delay means 23 to time interleave code S1 with respect to code S2. The output of delay 23 is coupled to modulator 24 to modulate the output of carrier source 22. The resultant outputs of modulators 21 and 24 are coupled to a linear adder 25 for combining on a time multiplex basis. The output of adder 25 is then coupled to power amplifier 26 whose output is coupled to antenna 27 for radiation therefrom.

Referring to Fig. 8, there is illustrated therein a detector arrangement which receives the output from the transmitter of Fig. 7 on antenna 28 for coupling to receiver 29 which recovers the time multiplexed code signals. The output of receiver 29 is coupled to both gates 30 and 31 which are appropriately activated by an S1 gate signal and S2 gate signal applied from sources 32 and 33, respectively. Upon occurrence of gate signal S1 from source 32, gate 30 is activated to separate code S1 from the time multiplexed code signals at the output of receiver 29. During occurrence of the S2 gate signal from source 33, gate 31 is activated to separate code signal S2 from the time multiplexed code signals in the output of receiver 29. The S1 code output from gate 30 is coupled to multiplier 34 and the S2 code output from gate 31 is coupled to multiplier 35. A code source 36 similar in structure to code source 20 generates a replica of codes S1 and S2 identified as code S1′ and code S2′. These two replicas from source 36 are coupled through delay devices 37 and 38 to the appropriate one of multipliers 34 and 35. When delay devices 37 and 38 are properly adjusted, the replicas S1′ and S2′ are coupled, respectively, to multipliers 34 and 35 in time coincidence with the received codes S1 and S2. When time coincidence is present, multipliers 34 and 35 will each produce an output of the same polarity which when linearly added in adder 39 results in the main peak or impulse output. At all other times where the replicas S1′ and S2′ are not in time coincidence with the received codes S1 and S2 there will be either no output from either multipliers 34 and 35, or there will be a spurious output from multiplier 35 and a spurious output from multiplier 34. These spurious outputs will have equal magnitude but opposite polarity so that when they are added together in adder 39 the result is a zero output from adder 39. For instance, assume S1 and S2 are, respectively, the mate codes #4 and #14. At time coincidence ($t=0$) a pulse having a magnitude of eight will appear at the output of multipliers 34 and 35 resulting in an impulse at the output of adder 39 having an amplitude of sixteen. If the delay between the replicas and the received codes are shifted in time to positions 2, 3, 5, 7 and 8, multipliers 34 and 35 will produce zero outputs resulting in zero outputs from linear adder 39. On the other hand, if the replicas and the received codes are delayed to time positions 4 and 6 one of multipliers 34 will produce a plus four unit amplitude output while the other of multipliers 35 will produce a minus four unit amplitude output which when added in linear adder 39 results in a zero output thereby providing the desired impulse correlation function after integration in the low pass filter 40.

In addition, there would be no loss in detection efficiency due to multiplexing. The output signal of each multiplier 34 and 35 would sum to eight at $t=0$ and being correlated would double or increase to sixteen in the linear adder 39. The noise in each bit would sum to $\sqrt{8}$ out of each multiplier and would be uncorrelated entering linear adder 39. Therefore, the output noise would increase by $\sqrt{8}\times\sqrt{2}=\sqrt{16}=4$. Hence, the improvement to signal-to-noise voltage over the input carrier signal-to-noise voltage would be $16/\sqrt{16}=16/4=4$ which is the same as detecting with a single correlation detector over a sixteen-bit code length.

The bit code class under consideration is unique in that the codes may be generated with simple two set binary sequences; there is a greater quantity of available discrete codes in a specified time band-width product than for a maximal length code class; an impulse autocorrelation function is realized making this code class ideally suited for an orthogonal pulse code modulation (PCM) system, that is, the intelligence may be coded orthogonally resulting in a PCM system with excellent transmission efficiency; and there is no loss in the detection efficiency due to multiplexing.

Referring to Fig. 9, there is illustrated therein in block diagram form a frequency multiplex transmitter comprising code source 20 to generate code signals S1 and code signals S2 which are code mates. Code siganls S1 are coupled to modulator 41 to modulate a carrier of frequency f1 from source 42. Code signals S2 are coupled to modulator 43 to modulate carrier of frequency f2 from source 44. The modulated outputs from modulators 41 and 43 are coupled to linear adder 45 whose output is coupled to power amplifier 46 and the output from this amplifier is finally coupled to antenna 47 for propagation therefrom.

Referring to Fig. 10, the frequency multiplexed code signals propagated from antenna 47 (Fig. 9) are received on antenna 48 and coupled to receiver 49 providing at its output the frequency multiplexed code signals. Filter 50 is coupled to the output of receiver 49 tuned to frequency f1 to recover the code signal S2 and filter 51 is coupled to receiver 49 tuned to frequency f2 to recover code signal S2. The code signals thus separated are then coupled to equipment identical to that described in connection with Fig. 8 to produce at the output thereof an impulse correlation function. The equipment includes multipliers 34 and 35, code source 36, delay means 37 and 38, linear adder 39 and low pass filter 40. The operation of this portion of Fig. 10 is identical to that described hereinabove with relation to Fig. 8 and thus further description is deemed unnecessary.

Referring to Figs. 11 to 18, there is disclosed therein diagrammatic illustrations of the operation of the correlation detection arrangement in accordance with the principles of this invention illustrating the production of an impulse autocorrelation function. In all of these illustrations code #4 is employed as code signal S1 and its replica S1′ and code #14 is code signal S2 and its replica S2′. The differences between various illustrations occur only in the particular delay between the replicas and their associated codes. Also, in these figures the following logical relationships are used to demonstrate the production of an impulse autocorrelation function:

$$0\times 1=-1$$

$$1\times 0=-1$$

$$1\times 1=+1$$

$$0\times 0=+1.$$

As illustrated in Fig. 11, the replicas and their associated codes are in time coincidence meaning that $t=0$. The output of multiplier 34 is illustrated with its summation being equal to $+8$. The output of multiplier 35 is illustrated with its summation being equal to $+8$. The output of adder 39 is also illustrated with its summation being equal to 16. Figs. 12, 13, 15, 17 and 18 illustrate, respectively, the condition when $t=1$, $t=2$, $t=4$, $t=6$ and $t=7$. In each of these illustrations the resultant outputs of multipliers 34 and 35 are illustrated along with their summation which in all cases is zero. The output of adder 39 is also illustrated showing that the summation of the individual bits equals zero. Figs. 14 and 16 illustrate how the spurious peaks in the code mates have equal amplitude but opposite polarity to produce the desired zero output from adder 39. It will be observed that the output of multiplier 34 in both figures results in a summation of $+4$ while the output from multiplier 35 results in a summation equal to -4. When these two outputs of multipliers 34 and 35 are added in adder 39, the resultant output is zero as illustrated. This is also verified by considering the linear addition of the individual bit outputs of multipliers 34 and 35 which again results in a zero output from adder 39.

Referring to Fig. 19, there is disclosed therein one form of a code source which may be utilized for code source 20 of Figs. 7 and 9 and the code source 36 of Figs. 8 and 10 with appropriate modification thereof to produce the desired replicas of the code signals produced by code sources 20. The code source 52 is the basic code source for the production of eight-bit code mates and is illustrated for the production of codes #4 and #14. Pulses from pulse generator 53 are coupled to delay lines 56 and 57 having eight outputs therealong time spaced to provide the desired bit spacing of the codes generated. The taps of delay line 56 are coupled directly to linear adder 61 to provide binary "1" and through inverters 54 to provide binary "0". As illustrated the circuit arrangement between delay line 56 and adder 61 generates code #14. The taps of delay line 57 are coupled directly to linear adder 64 to provide binary "1" and through inverters 55 to provide binary "0". As illustrated the circuit arrangement between delay line 57 and adder 61 generates code #4. With

delay means 65 set to zero, switch 66 positioned as illustrated, and switch 67 positioned as illustrated, it would be possible to provide code #4 as one of the codes S1 and S2 and code #14 as the other of the codes S1 and S2.

By moving switches 66 and 67 to their other position, it would be possible to provide a code source 68 providing sixteen-bit code mates. As illustrated in Fig. 19, the sixteen-bit code mates are codes A4 and A4′ as illustrated in rows D and E, Fig. 2 and tabulated in Fig. 3. By adjusting delay means 65 to produce the delays illustrated in Fig. 2, it would also be possible to provide the seven other code mates tabulated in Fig. 3, the production of which is diagrammatically illustrated in Fig. 2. To produce the sixteen-bit code mates, the output from delay means 65 and the output from adder 61 are coupled to multiplexer 69 to interleave code #4 and code #14 to produce code A4, or any of the other codes B4 to H4 depending upon the setting of the delay in delay means 65. The output from adder 61 is also coupled to phase inverter 70 to provide the complemented code #14 which in turn is coupled to multiplixer 71 together with code #4 from delay means 65. The two inputs to multiplever 71 are interleaved to produce code A4′, or any of the other codes B4′ to H4′. The output from source 68 is provided by switch 72 set in the position illustrated and switch 73 set in the position illustrated.

To produce thirty-two-bit code mates, code source 74 is provided which adds to the components of sources 52 and 68, multiplexer 75, phase inverter 76 and multiplexer 77. Switches 72 and 73 are set to their other position so that the output of multiplexer 69 is coupled to multiplexer 75 together with the output from multiplexer 71 through delay means 78 which provides the same function as delay means 65 to increase the number of code mates having thirty-two bits. The operation of multiplexer 75 is to interleave code A4 and code A4′ to provide code A at the output of source 74. The output from delay means 78 is coupled to phase inverter 76 to produce the complemented version of code A4′. The output from inverter 76 is coupled to multiplexer 77 together with the output of multiplexer 69 to produce code A′, the other output of source 74.

The description of the code sources of Fig. 19 has been directed to the utilization of a given one of the code mates listed in Fig. 1 and the extension technique applied to these code mates to generate sixteen-bit code mates and thirty-two-bit code mates. It is to be remembered that the other two code mates identified in Fig. 1 can likewise be generated and extended to provide sixteen- and thirty-two-bit code mates by merely changing the connection between delay line 56 and linear adder 61, and between delay line 57 and linear adder 64 to provide the code format for the code mates of eight bits.

It has been previously mentioned that the code mates generated and detected in accordance with the principles of this invention are of the pseudo-noise type. This can be demonstrated by considering their interference properties which in effect are determined by the cross correlation properties of the multiplexed code mates. The cross correlation function can readily be obtained from the following equation:

$$\phi_{ab}(t)=\frac{1}{N}\sum_{n=1}^{n=N} a_n b_{(n+t)} \qquad (19)$$

where a and b refer to the respective code signals being cross-correlated, n the position in the code signal of a digit under cross-correlation, and t the delay between the nth digits of the two code signals.

The cross correlation properties of several code pairs have been identified and the results in general are similar. A typical example is the code mates #3 and #15 cross correlated with the code mates #4 and #14 which is illustrated in Fig. 20.

From Fig. 20, the rms value is $\sqrt{\frac{64+16\times 4}{8}}=4$ when averaged over T. Since the peak output of the autocorrelation function at $t=0$ multiplied by N is equal to 16, the protection ratio would be $\sqrt{16}=4$. Hence, the peak output reduced by the protection ratio is equal to $\frac{1}{4}$ (16)=4 which is equal to the rms value of $N\phi_{ab}(t)$. That is, on the average, the cross correlation between two code mates is $1/\sqrt{TW}$ times the value of the autocorrelation function at $t=0$. This is the condition which exists between two pseudo-noise codes and applies to the code class of this invention.

WHAT WE CLAIM IS:—

1. A correlation type pulse signalling system in which binary coded signals are used, the signals being so coded as to provide pair of cooperating "code-mates", the mates of any given pair having predeterminedly-related and co-operating autocorrelation functions whereby upon transmission of signals corresponding to a given pair of "code-mates" to a distant receiver and detection of the individual "mates" of the pair upon reception thereat by respective autocorrelation detectors, followed by linear addition of the respective detector outputs, an "impulse autocorrelation function" (as herein defined) is derived, providing an impulse output at a given time and zero output at all other times within the periodic time of a coded signal comprising a pair of "code-mates".

2. A system as claimed in claim 1 wherein the individual "code-mates" have autocorrelation functions including a main peak occurring at the time of the first bit of the respective code mate, zero at times coincident with other bits of the "code-mate", and spurious peaks at other times coincident with yet other bits of the "code-mate" having equal magnitude but opposite to corresponding bits of the cooperating "code-mate", whereby the individual autocorrelation functions of the two "code-mates" of the pair co-operate on linear addition to provide an impulse autocorrelation function.

3. A system as claimed in claim 2 wherein said binary coded signals forming said "code-mates" are multiplexed for transmission to said receiver.

4. A system as claimed in claim 3, wherein said multiplexing is effected in time.

5. A system as claimed in claim 3, wherein said multiplexing is effected in frequency.

6. A method of deriving coded signals for use in the system as claimed in any preceding claim which comprises generating a plurality of binary coded signals each having a different given autocorrelation function the coding being such that some coded signals are "code-mates" of others, and selecting at least some of said generated signals to provide signal pairs of "code-mates" such that on detection of the two individual "code-mates" of a pair, the autocorrelation functions of the detected signals may be added to produce an impulse autocorrelation function for each said pair.

7. A method as claimed in claim 6 in which further pairs of "code-mates" are derived from said generated signals by interleaving the binary digits of the separate signals (hereinafter referred to as said first and second coded signals) of a specified one of said original pairs of code mates to produce a third coded signal having a third autocorrelation function; complementing a given one of said first and second coded signals; and interleaving the other of said first and second coded signals and said complemented one of said coded signals to produce a fourth coded signal which is a "code-mate" of the third and having a fourth autocorrelation function predeterminedly related to said third autocorrelation function to produce upon autocorrelation detection of said third and fourth coded signals followed by addition an impulse autocorrelation function.

8. A method as claimed in claim 7 in which still further pairs of "code-mates" are derived from said generated signals, in which one of said coded signals of said specified one of said signal pairs is displaced with respect to the other of said coded signals of said specified pair a predetermined number of time positions (less than the number of digits forming said coded signals) before interleaving digits as aforesad to derive said third and said fourth coded signals.

9. A method as claimed in claim 7 or 8 applied to a plurality (including all) of said original pairs of "code-mates" to derive still further pairs of "code-mates" having respectively the necessary co-operating autocorrelation functions to produce an impulse autocorrelation function upon autocorrelation detection and addition.

10. A method as claimed in claim 7, 8 or 9 in which the procedure for deriving said further pairs of "code-mates" by interleaving is repeated, as described, using the further pairs in place of the original pairs to derive still further pairs of "code-mates" having respectively the necessary co-operating autocorrelation functions to produce an impulse autocorrelation function upon autocorrelation detection and addition.

11. A detector for use in the receiver of a system as claimed in any one of claims 1 to 5 for providing an impulse autocorrelation function at its output when connected at its input to a source of both a first code signal having a first autocorrelation function and a second code signal having a second autocorrelation function predeterminedly related to said first autocorrelation function in such a way that the combined autocorrelation functions when linearly added form an impulse function

including an impulse at a given time and zero at all other times within the periodic time of either signal; comprising:

first means coupled to said source to separately autocorrelate said first and second code signals; and

second means coupled to said first means to combine the resultant signals of said autocorrelation to produce said impulse autocorrelation function.

12. A detector according to claim 11, wherein said first and second code signals of said source are multiplexed; and said first means includes third means coupled to said source to separate said first and second code signals from said multiplexed first and second code signals.

13. A detector according to claim 12, wherein said first and second code signals of said source are time multiplexed; and said third means includes a first time coincident gating means coupled to said source to separate said first code signal from said time multiplexed first and second code signals, and a second time coincident gating means coupled to said source to separate said second code signal from said time multiplexed first and second code signals.

14. A detector according to claim 12, wherein said first and second code signals of said source are frequency multiplexed; and said third means includes a first filter means coupled to said source to separate said first code signal from said frequency multiplexed first and second code signals, and a second filter means coupled to said source to separate said second code signal from said frequency multiplexed first and second code signals.

15. A detector according to claim 12, wherein said second means includes linear adder means to combine said resultant signals.

16. A detector according to claim 12, wherein said first means further includes fourth means coupled to said third means to autocorrelate said first code signal with a replica thereof and said second code signal with a replica thereof.

17. A detector according to claim 16, wherein said fourth means includes fifth means to generate a replica of said first code signal, sixth means to generate a replica of said second code signal, first multiplier means coupled to said third means and said fifth means, and second multiplier means coupled to said third means and said sixth means.

18. A detector according to claim 17, wherein said second means includes linear adder means coupled to said first and second multiplier means.

19. A detector according to claim 18, wherein said second means further includes an integrator means coupled to the output of said linear adder means.

20. A correlation type pulse signalling system substantially as herein described with reference to the accompanying drawings.

21. A method of deriving coded signals for use in a correlation type pulse signalling system, substantially as herein described with reference to, and as shown in, Figs. 1 to 6, and Figs. 11 to 20 of the accompanying drawings.

22. A detector for use in a correlation type pulse signalling system, substantially as herein described with reference to, and as shown in, Fig. 8 or 10 of the accompanying drawings.

S. R. CAPSEY
Chartered Patent Agent
For the Applicants

Printed for Her Majesty's Stationery Office, by the Courier Press, Leamington Spa, 1971. Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1246142 COMPLETE SPECIFICATION

10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

FIG.1

MATES MATES MATES

CODES	FORMAT								Nx AUTOCORRELATION FUNCTION [NØaa(t)]							
1	1	0	0	0	0	0	0	0	+8	+4	+4	+4	+4	+4	+4	+4
2	1	1	0	0	0	0	0	0	+8	+4	0	0	0	0	0	+4
3	1	0	1	0	0	0	0	0	+8	0	+4	0	0	0	+4	0
4	1	0	0	1	0	0	0	0	+8	0	0	+4	0	+4	0	0
5	1	0	0	0	1	0	0	0	+8	0	0	0	+8	0	0	0
6	1	1	1	0	0	0	0	0	+8	+4	0	-4	-4	-4	0	+4
7	1	1	0	1	0	0	0	0	+8	0	0	0	-4	0	0	0
8	1	1	0	0	1	0	0	0	+8	0	-4	0	+4	0	-4	0
9	1	1	0	0	0	1	0	0	+8	0	-4	0	+4	0	-4	0
10	1	1	0	0	0	0	1	0	+8	0	0	0	-4	0	0	0
11	1	0	1	0	1	0	0	0	+8	-4	+4	-4	+4	-4	+4	-4
12	1	0	1	0	0	1	0	0	+8	-4	0	+4	-4	+4	0	-4
13	1	1	1	1	0	0	0	0	+8	+4	0	-4	-8	-4	0	+4
14	1	1	1	0	1	0	0	0	+8	0	0	-4	0	-4	0	0
15	1	1	1	0	0	1	0	0	+8	0	-4	0	0	0	-4	0
16	1	1	0	1	0	1	0	0	+8	-4	0	0	0	0	0	-4
17	1	1	0	1	0	0	1	0	+8	-4	0	+4	-8	+4	0	-4
18	1	1	0	0	1	1	0	0	+8	0	-8	0	+8	0	-8	0
19	1	0	1	0	1	0	1	0	+8	-8	+8	-8	+8	-8	+8	-8

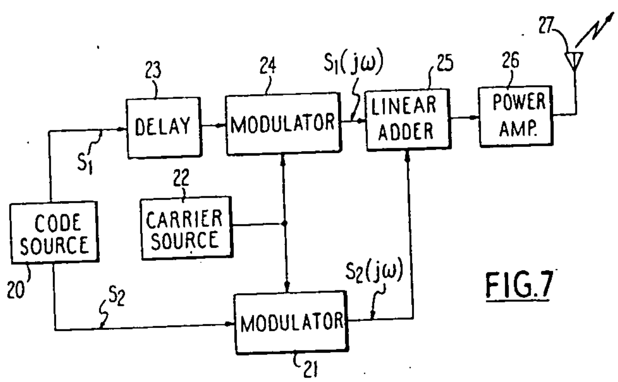


FIG.7

B.

FIG. 2

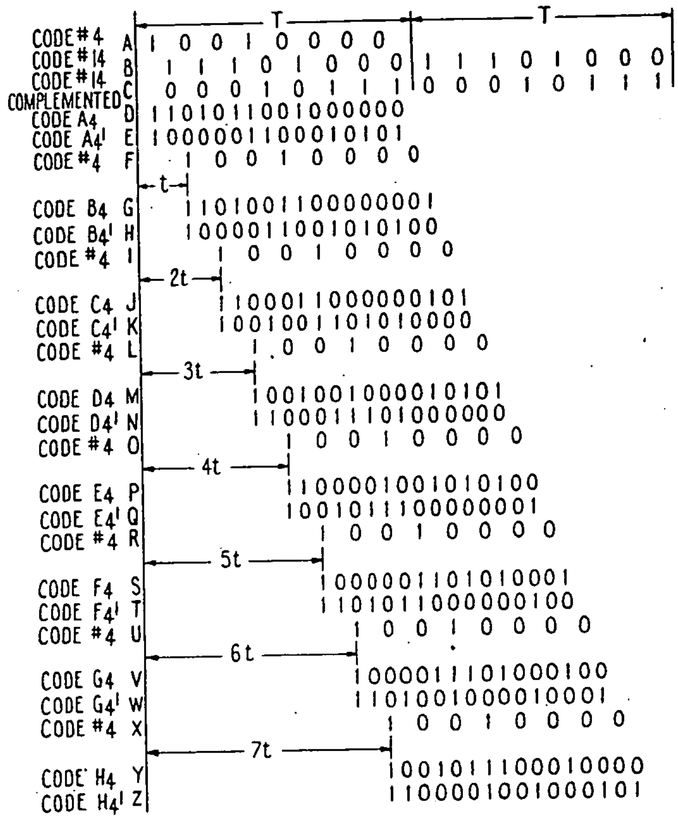

T
T
CODE #4 A 1 0 0 1 0 0 0 0
CODE #14 B 1 1 1 0 1 0 0 0 1 1 1 0 1 0 0 0
CODE #14 COMPLEMENTED C 0 0 0 1 0 1 1 1 0 0 0 1 0 1 1 1
CODE A4 D 1101011001000000
CODE A4' E 1000001100010101
CODE #4 F 1 0 0 1 0 0 0 0
t
CODE B4 G 1101001100000001
CODE B4' H 1000011001010100
CODE #4 I 1 0 0 1 0 0 0 0
2t
CODE C4 J 1100011000000101
CODE C4' K 1001001101010000
CODE #4 L 1 0 0 1 0 0 0 0
3t
CODE D4 M 1001001000010101
CODE D4' N 1100011101000000
CODE #4 O 1 0 0 1 0 0 0 0
4t
CODE E4 P 1100001001010100
CODE E4' Q 1001011100000001
CODE #4 R 1 0 0 1 0 0 0 0
5t
CODE F4 S 1000001101010001
CODE F4' T 1101011000000100
CODE #4 U 1 0 0 1 0 0 0 0
6t
CODE G4 V 1000011101000100
CODE G4' W 1101001000010001
CODE #4 X 1 0 0 1 0 0 0 0
7t
CODE H4 Y 1001011100010000
CODE H4' Z 1100001001000101

FIG. 3

CODES	FORMAT																Nx AUTO CORRELATION FUNCTION [NØaa(t)]															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A4	1	1	0	1	0	1	1	0	0	1	0	0	0	0	0	0	+16	0	0	+4	0	0	0	-4	0	-4	0	0	0	+4	0	0
A4'	1	0	0	0	0	0	1	1	0	0	0	1	0	1	0	1	+16	0	0	-4	0	0	0	+4	0	+4	0	0	0	-4	0	0
B4	1	1	0	1	0	0	1	1	0	0	0	0	0	0	0	1	+16	+4	0	0	0	-4	0	0	0	0	0	-4	0	0	0	+4
B4'	1	0	0	0	0	1	1	0	0	1	0	1	0	1	0	0	+16	-4	0	0	0	+4	0	0	0	0	0	+4	0	0	0	-4
C4	1	1	0	0	0	1	1	0	0	0	0	0	0	1	0	1	+16	+4	0	-4	0	0	0	0	0	0	0	0	0	-4	0	+4
C4'	1	0	0	1	0	0	1	1	0	1	0	1	0	0	0	0	+16	-4	0	+4	0	0	0	0	0	0	0	0	0	+4	0	-4
D4	1	0	0	1	0	0	1	0	0	0	0	1	0	1	0	1	+16	-4	0	+4	0	0	0	0	0	0	0	0	0	+4	0	-4
D4'	1	1	0	0	0	1	1	1	0	1	0	0	0	0	0	0	+16	+4	0	-4	0	0	0	0	0	0	0	0	0	-4	0	+4
E4	1	1	0	0	0	0	1	0	0	1	0	1	0	1	0	0	+16	-4	0	0	0	+4	0	0	0	0	0	+4	0	0	0	-4
E4'	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	1	+16	+4	0	0	0	-4	0	0	0	0	0	-4	0	0	0	+4
F4	1	0	0	0	0	0	1	1	0	1	0	1	0	0	0	1	+16	0	0	-4	0	0	0	+4	0	+4	0	0	0	-4	0	0
F4'	1	1	0	1	0	1	1	0	0	0	0	0	0	1	0	0	+16	0	0	+4	0	0	0	-4	0	-4	0	0	0	+4	0	0
G4	1	0	0	0	0	1	1	1	0	1	0	0	0	1	0	0	+16	0	0	0	0	-4	0	+4	0	+4	0	-4	0	0	0	0
G4'	1	1	0	1	0	0	1	0	0	0	0	1	0	0	0	1	+16	0	0	0	0	+4	0	-4	0	-4	0	+4	0	0	0	0
H4	1	0	0	1	0	1	1	1	0	0	0	1	0	0	0	0	+16	0	0	0	0	+4	0	-4	0	-4	0	+4	0	0	0	0
H4'	1	1	0	0	0	0	1	0	0	1	0	0	0	1	0	1	+16	0	0	0	0	-4	0	+4	0	+4	0	-4	0	0	0	0

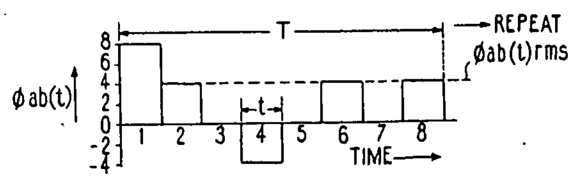
FIG. 4

CODES	FORMAT																Nx AUTO CORRELATION FUNCTION [N $\phi aa(t)$]															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A_2	1	1	1	1	0	0	0	1	0	0	0	1	0	0	0	0	+16	+4	0	-4	0	0	0	0	0	0	0	0	0	-4	0	+4
A_2'	1	0	1	0	0	1	0	0	0	1	0	0	0	1	0	1	+16	-4	0	+4	0	0	0	0	0	0	0	0	0	+4	0	-4
B_2	1	1	1	0	0	1	0	0	0	1	0	0	0	0	0	1	+16	+4	0	0	0	-4	0	0	0	0	0	-4	0	0	0	+4
B_2'	1	0	1	1	0	0	0	1	0	0	0	1	0	1	0	0	+16	-4	0	0	0	+4	0	0	0	0	0	+4	0	0	0	-4
C_2	1	0	1	1	0	0	0	1	0	0	0	0	0	1	0	1	+16	0	0	+4	0	0	0	-4	0	-4	0	0	0	+4	0	0
C_2'	1	1	1	0	0	1	0	0	0	1	0	1	0	0	0	0	+16	0	0	-4	0	0	0	+4	0	+4	0	0	0	-4	0	0
D_2	1	1	1	0	0	1	0	0	0	0	0	1	0	1	0	0	+16	0	0	0	0	+4	0	-4	0	-4	0	+4	0	0	0	0
D_2'	1	0	1	1	0	0	0	1	0	1	0	0	0	0	0	1	+16	0	0	0	0	-4	0	+4	0	+4	0	-4	0	0	0	0
E_2	1	0	1	1	0	0	0	0	0	1	0	1	0	0	0	1	+16	0	0	0	0	-4	0	+4	0	+4	0	-4	0	0	0	0
E_2'	1	1	1	0	0	1	0	1	0	0	0	0	0	1	0	0	+16	0	0	0	0	+4	0	-4	0	-4	0	+4	0	0	0	0
F_2	1	1	1	0	0	0	0	1	0	1	0	0	0	1	0	0	+16	0	0	-4	0	0	0	+4	0	+4	0	0	0	-4	0	0
F_2'	1	0	1	1	0	1	0	0	0	0	0	1	0	0	0	1	+16	0	0	+4	0	0	0	-4	0	-4	0	0	0	+4	0	0
G_2	1	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	+16	-4	0	0	0	+4	0	0	0	0	0	+4	0	0	0	-4
G_2'	1	1	1	1	0	0	0	0	0	1	0	0	0	1	0	0	+16	+4	0	0	0	-4	0	0	0	0	0	-4	0	0	0	+4
H_2	1	0	1	1	0	1	0	0	0	1	0	0	0	1	0	0	+16	-4	0	+4	0	0	0	0	0	0	0	0	0	+4	0	-4
H_2'	1	1	1	0	0	0	0	1	0	0	0	1	0	0	0	1	+16	+4	0	-4	0	0	0	0	0	0	0	0	0	-4	0	+4

FIG. 5

CODES	FORMAT																Nx AUTO CORRELATION FUNCTION [N Øaa(t)]															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
A3	1	1	0	1	1	1	0	0	0	0	0	1	0	0	0	0	+16	+4	0	0	0	0	0	-4	0	-4	0	0	0	0	0	+4
A3'	1	0	0	0	1	0	0	1	0	1	0	0	0	1	0	1	+16	-4	0	0	0	0	0	+4	0	+4	0	0	0	0	0	-4
B3	1	1	0	1	1	0	0	0	0	1	0	0	0	0	0	1	+16	+4	0	0	0	0	0	-4	0	-4	0	0	0	0	0	+4
B3'	1	0	0	0	1	1	0	1	0	0	0	1	0	1	0	0	+16	-4	0	0	0	0	0	+4	0	+4	0	0	0	0	0	-4
C3	1	1	0	0	1	0	0	1	0	0	0	0	0	1	0	1	+16	0	0	+4	0	-4	0	0	0	0	0	-4	0	+4	0	0
C3'	1	0	0	1	1	1	0	0	0	1	0	1	0	0	0	0	+16	0	0	-4	0	+4	0	0	0	0	0	+4	0	-4	0	0
D3	1	0	0	0	1	1	0	0	0	0	0	1	0	1	0	1	+16	0	0	-4	0	+4	0	0	0	0	0	+4	0	-4	0	0
D3'	1	1	0	1	1	0	0	1	0	1	0	0	0	0	0	0	+16	0	0	+4	0	-4	0	0	0	0	0	-4	0	+4	0	0
E3	1	0	0	1	1	0	0	0	0	1	0	1	0	1	0	0	+16	-4	0	0	0	0	0	+4	0	+4	0	0	0	0	0	-4
E3'	1	1	0	0	1	1	0	1	0	0	0	0	0	0	0	1	+16	+4	0	0	0	0	0	-4	0	-4	0	0	0	0	0	+4
F3	1	1	0	0	1	0	0	1	0	1	0	1	0	0	0	0	+16	-4	0	0	0	0	0	+4	0	+4	0	0	0	0	0	-4
F3'	1	0	0	1	1	1	0	0	0	0	0	0	0	1	0	1	+16	+4	0	0	0	0	0	-4	0	-4	0	0	0	0	0	+4
G3	1	0	0	0	1	1	0	1	0	1	0	0	0	0	0	1	+16	0	0	-4	0	+4	0	0	0	0	0	+4	0	-4	0	0
G3'	1	1	0	1	1	0	0	0	0	0	0	1	0	1	0	0	+16	0	0	+4	0	-4	0	0	0	0	0	-4	0	+4	0	0
H3	1	0	0	1	1	1	0	1	0	0	0	0	0	1	0	0	+16	0	0	+4	0	-4	0	0	0	0	0	-4	0	+4	0	0
H3'	1	1	0	0	1	0	0	0	0	1	0	1	0	0	0	1	+16	0	0	-4	0	+4	0	0	0	0	0	+4	0	-4	0	0

FIG. 20



1246142 COMPLETE SPECIFICATION
10 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 6

CODE A (CODE A_4 INTERLEAVED WITH ITS MATE CODE A_4')																															
FORMAT																															
1	1	1	0	0	0	1	0	0	0	1	0	1	1	0	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	1
Nx AUTO CORRELATION FUNCTION [$N\phi aa(t)$]																															
+32	0	0	0	0	+4	0	-4	0	0	0	+8	0	+4	0	+4	0	+4	0	+4	0	+8	0	0	0	-4	0	+4	0	0	0	0
CODE A' (CODE A_4 INTERLEAVED WITH COMPLIMENTED MATE CODE A_4')																															
FORMAT																															
1	0	1	1	0	1	1	1	0	1	1	1	1	0	0	0	0	1	1	1	0	1	0	0	0	1	0	0	0	1	0	0
Nx AUTO CORRELATION FUNCTION [$N\phi aa(t)$]																															
+32	0	0	0	0	-4	0	+4	0	0	0	-8	0	-4	0	-4	0	-4	0	-4	0	-8	0	0	0	+4	0	-4	0	0	0	0
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32

FIG. 6

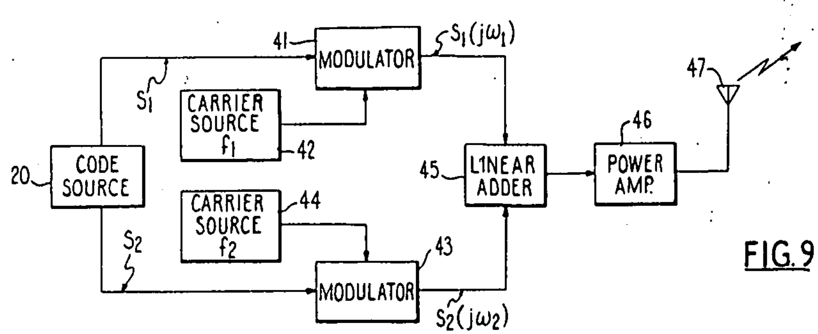


FIG. 9

FIG. 8

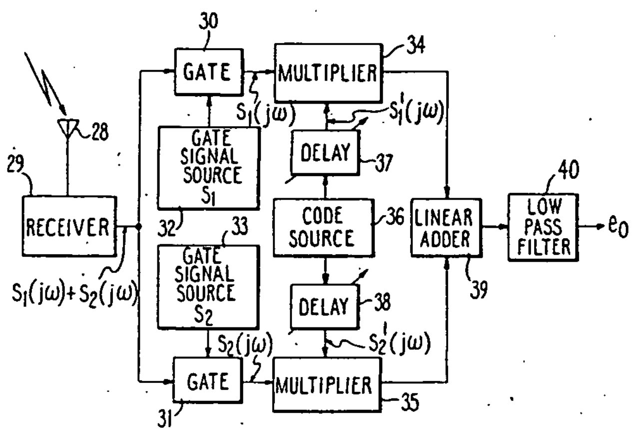

30
GATE
MULTIPLIER
34
$S_1(j\omega)$
$S_1'(j\omega)$
28
29
GATE SIGNAL SOURCE S_1
DELAY
37
40
RECEIVER
32
33
CODE SOURCE
36
LINEAR ADDER
LOW PASS FILTER
e_0
GATE SIGNAL SOURCE S_2
DELAY
38
39
$S_1(j\omega)+S_2(j\omega)$
$S_2(j\omega)$
$S_2'(j\omega)$
GATE
MULTIPLIER
35
31

FIG. 10

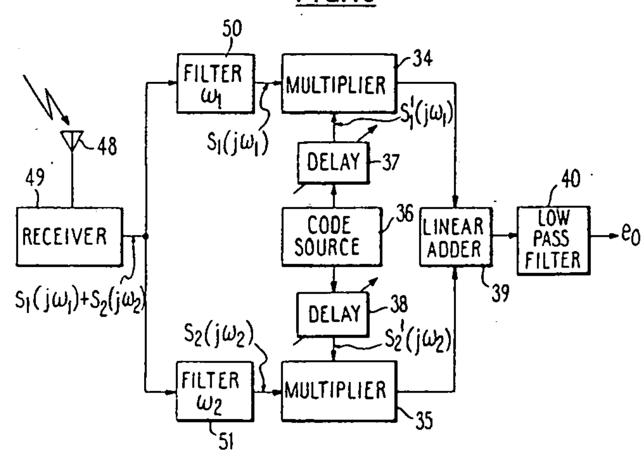

50
FILTER ω_1
MULTIPLIER
34
$S_1'(j\omega_1)$
$S_1(j\omega_1)$
48
49
DELAY
37
40
RECEIVER
CODE SOURCE
36
LINEAR ADDER
LOW PASS FILTER
e_0
$S_1(j\omega_1)+S_2(j\omega_2)$
39
DELAY
38
$S_2(j\omega_2)$
$S_2'(j\omega_2)$
FILTER ω_2
MULTIPLIER
35
51

FIG. 11

t=0 j $S_1=S_1'$=CODE #4 j $S_2=S_2'$=CODE #14

S_1	1	0	0	1	0	0	0	0	
S_1'	1	0	0	1	0	0	0	0	
OUTPUT MULTIPLIER 34	+1	+1	+1	+1	+1	+1	+1	+1	Σ = +8
OUTPUT ADDER 39	+2	+2	+2	+2	+2	+2	+2	+2	Σ = +16
OUTPUT MULTIPLIER 35	+1	+1	+1	+1	+1	+1	+1	+1	Σ = +8
S_2	1	1	1	0	1	0	0	0	
S_2'	1	1	1	0	1	0	0	0	

FIG. 12

t=1 j $S_1=S_1'$=CODE #4 j $S_2=S_2'$=CODE #14

S_1	1	0	0	1	0	0	0	0	
S_1'	0	1	0	0	1	0	0	0	
OUTPUT MULTIPLIER 34	-1	-1	+1	-1	-1	+1	+1	+1	Σ = 0
OUTPUT ADDER 39	-2	0	+2	-2	-2	0	+2	+2	Σ = 0
OUTPUT MULTIPLIER 35	-1	+1	+1	-1	-1	-1	+1	+1	Σ = 0
S_2	1	1	1	0	1	0	0	0	
S_2'	0	1	1	1	0	1	0	0	

FIG. 13

t=2 j $S_1=S_1'$=CODE #4 j $S_2=S_2'$=CODE #14

S_1	1	0	0	1	0	0	0	0	
S_1'	0	0	1	0	0	1	0	0	
OUTPUT MULTIPLIER 34	-1	+1	-1	-1	+1	-1	+1	+1	Σ = 0
OUTPUT ADDER 39	-2	0	0	-2	+2	0	0	+2	Σ = 0
OUTPUT MULTIPLIER 35	-1	-1	+1	-1	+1	+1	-1	+1	Σ = 0
S_2	1	1	1	0	1	0	0	0	
S_2'	0	0	1	1	1	0	1	0	

FIG. 14

t=3 j $S_1=S_1'$=CODE #4 j $S_2=S_2'$=CODE #14

S_1	1	0	0	1	0	0	0	0	
S_1'	0	0	0	1	0	0	1	0	
OUTPUT MULTIPLIER 34	-1	+1	+1	+1	+1	+1	-1	+1	Σ = +4
OUTPUT ADDER 39	-2	0	0	0	+2	0	0	0	Σ = 0
OUTPUT MULTIPLIER 35	-1	-1	-	-1	+1	-1	+1	-1	Σ = -4
S_2	1	1	1	0	1	0	0	0	
S_2'	0	0	0	1	1	1	0	1	

FIG. 15

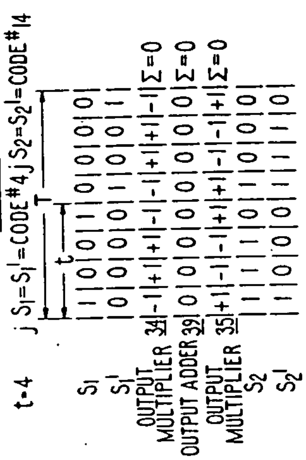


FIG. 16

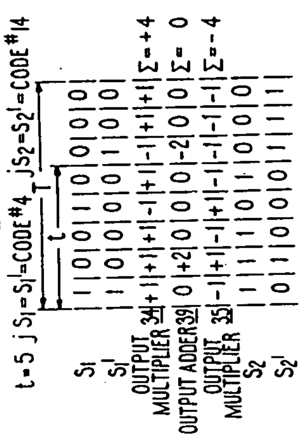


FIG. 17

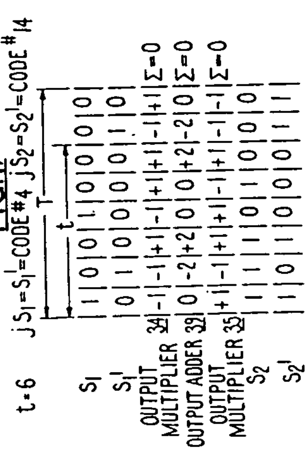


FIG. 18

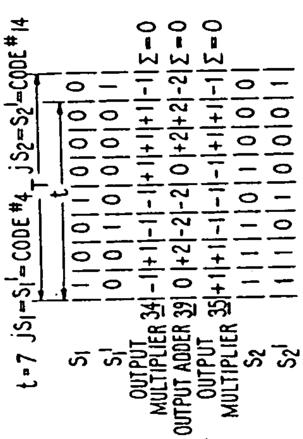
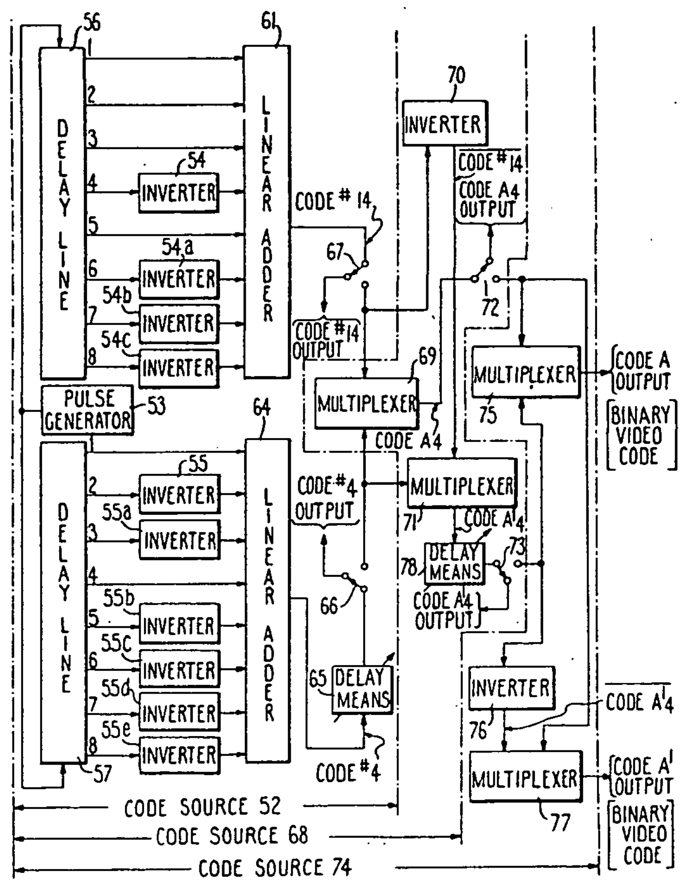


FIG. 19


DELAY LINE
LINEAR ADDER
INVERTER
PULSE GENERATOR
MULTIPLEXER
DELAY MEANS
CODE # 14
CODE #14 OUTPUT
CODE #4 OUTPUT
CODE #4
CODE A4
CODE A4 OUTPUT
CODE A OUTPUT
BINARY VIDEO CODE
CODE A'4
CODE A' OUTPUT
CODE SOURCE 52
CODE SOURCE 68
CODE SOURCE 74